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18 JUN 1990

Studies have been done

Question 19

Our efforts to understand the perception of complex auditory stimuli produced four different research undertakings. ~~We have been studying~~, both with computer simulations and human listeners, the most precise psychophysical procedure to estimate a discrimination threshold. ~~We have perfected~~ a technique to determine the listener's sensitivity to synchrony in envelope modulation produced at two separate frequency regions, and have measured such sensitivity using a variety of different stimulus parameters. Sensitivity to modulation synchrony is essentially independent of the locus of the two frequency bands. ~~We have also studied~~ temporal factors that influence the ability to discriminate an increment in the level of a single component of a multi-tonal complex. Very slight differences in the temporal onset (>20 msec.) of tone and complex strongly influence the ability to make such discrimination even when the entire stimulus lasts 500 msec. Finally, we continue to study the estimates of spectral weights used in such intensity discrimination tasks, using the COSS analysis. suggested by Dr. Bruce Berg.

was perfected

Studies have also been done on

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June 13, 1990

Annual Report for period 14 April 1989 - 15 April 1990

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18 JUN 1990

PROGRESS REPORT

This progress report covers the period from April 14, 1989 to April 15, 1990. We begin with a list of the papers published or submitted for publication. The narrative portion of the progress report will refer to these publications.

There are four topic areas that occupied our efforts during the past year. These are used as the major headings in our review.

PUBLICATIONS

1) Raney, J.J., Richards, V.M., Onsan, Z.A., and Green, D.M., (1989) "Signal uncertainty and psychometric functions in profile analysis." Journal of the Acoustical Society of America, 86, 954-960.

2) Green, D.M., Richards, V.M., and Forrest, T.G., (1989) "Stimulus step size and heterogeneous stimulus conditions in adaptive psychophysics." Journal of the Acoustical Society of America, 86, 629-636.

3) Berg, B.G., (1989) "Analysis of weights in multiple observation tasks." Journal of the Acoustical Society of America, 86, 1743-1746.

4) Green, D. M., "Stimulus Selection in Adaptive Psychophysical Procedures" Accepted by the Journal of the Acoustical Society of America to appear in the fall of 1990.

5) Green, D. M., Richards, V. M., Onsan, Z. A., "Sensitivity to Envelope Coherence" Journal of the Acoustical Society of America, 87, 323-329.

6) Green, D. M., (1989) "Profile Analysis" International Congress of Acoustics, Belgrade, Yugoslavia, Vol. 1, Theme 5S, Belgrade, Yugoslavia.

7) Berg, B. G., "Observer Efficiency and Weights in a Multiple Observation Task" Submitted for publication in the Journal of the Acoustical Society of America.

7) Berg, B. G., and Green, D. G., (1990) "Spectral Weights in Profile Listening" To appear in Vol. 87, Journal of the Acoustical Society of America.

8) Green, D. M., and Berg, B. G., "Spectral Weights and the Profile Bowl" Submitted for a special issue on 'Hearing and Speech' of the Quarterly Journal of Experimental Psychology

Invited Presentations

I gave an invited address at the International Congress of Acoustics, August 25, 1989, in Belgrade (see Ref. 6 above). I also gave an invited presentation on 'Central Processes in Auditory Detection, Discrimination, and Recognition' at the Acoustical Society of America meeting in St. Louis in December, 1989.

RESEARCH TOPICS

1. Adaptive Psychophysical Methods.

We continue to follow developments in the area of adaptive psychophysics, because practically all our experiments use this kind of procedure to measure the detectability of the signal. One of our efforts in this area has been published (Ref. 2). Since that paper, we have been concerned with the appropriate stimulus level to use in adaptive tasks--where should the stimulus be placed on each trial to minimize the variance of the threshold estimate? A recent publication by Laming and Marsh (1988-Perception and Psychophysics 44, p. 99-107) was the original stimulus for this research.

Laming and Marsh showed that, in a maximum likelihood procedure, the stimulus should be presented at such a level as to produce 94% correct responses in two-alternative forced-choice tasks. This seemed incredible to me. That would mean the observer makes only 3 errors in a 50-trial block! Since the popular two-down one-up procedure of Levitt generates nearly 30% errors (15 errors per 50 trials), I decided to look into this matter using both monte carlo simulations and human listeners. The abstract of my presentation at the memorial session for Dr. J. P. Egan summarizes my findings.

> A common misconception is that the stimulus should be presented near the threshold value in an adaptive psychophysical procedure. For maximum likelihood procedures, recent work by Laming, Watson, and Pelli shows that the stimulus should be presented at a relatively high level. For some psychometric functions, they found the optimal stimulus placement level produces 84 to 94% correct in a two-alternative forced-choice task. This result is particularly disquieting, because the popular two-down one-up rule tracks a relatively low percentage of correct responses, 70.7%. Our computer simulations, using a variety of psychometric functions, confirm the validity of their analysis. These simulations also demonstrate that the precise form of the

psychometric function is not critical in achieving high efficiencies. Finally, data from human listeners indicate that the standard deviation of threshold estimates is approximately twice as large when the stimulus presented on each trial is at a stimulus level corresponding to 70.7% rather than 94% correct.

This work has been accepted for publication (Ref. 4). We are starting to use the maximum likelihood procedure in our laboratory. I am too cautious to change completely at this time, but we are beginning to develop experience with these procedures in a variety of different experimental tasks.

2. Synchrony Detection--Comodulation Effects

A paper finished while Dr. Richards was in the process of leaving the laboratory has been published (Ref. 5.) In that research, we measured how well listeners can discriminate whether the amplitude modulation of two sinusoids is in-phase or out-of-phase. By titrating on the depth of modulation, we can map out the sensitivity of the auditory system to coherence between envelopes present in different frequency regions. We systematically varied the center frequencies of the two sinusoids, their frequency difference, their modulation rates, and their sensation levels. This study provides the most complete data on the auditory ability to detect such correlations under a variety of stimulus conditions.

3. Temporal Effects

Two efforts are now underway to assess temporal properties of the process of detecting differences in complex auditory stimuli.

A. Raney's Thesis

One effort is the thesis topic of Dr. Jill Raney. It concerns the ability to discriminate the frequency of amplitude modulation. Dr. Raney has completed a draft of this work, and it will be submitted shortly. Let me briefly describe the experimental procedure.

The listener hears two sounds, a sinusoidal carrier amplitude modulated at frequency, f_m, and frequency, $f_m + \Delta f_m$. The task is to discriminate between the two, that is, to discriminate which envelope is modulating at the higher frequency. She titrates on the difference in modulation frequency, Δf_m. Carrier frequency and depth of modulation are two experimental parameters. In addition, she has explored how uncertainty about the value of the carrier frequency affects such discriminations. For low frequencies of modulation, it is unimportant whether the carrier frequency is fixed or varies randomly on each presentation. The listeners can discriminate a 10% change in modulation frequency, and we believe the basis of this discrimination is simple temporal discrimination of the change in rate. At higher modulation frequencies, as you might expect, discrimination is best when the carrier frequency is fixed. If the carrier frequency of the two sounds changes on each presentation, the task becomes much more difficult. This difference probably arises because the listener, in the fixed carrier condition, can discriminate the frequency of the lower side band of the modulation frequency. With random carrier location, this cue is abolished and the discrimination worsens. Using still a third condition, she demonstrates that the cue for discriminating the change in modulation rate with the random carrier frequency is, in all probability, a pitch cue. Thus, by noting where the functions diverge, she is able to estimate the boundary in time between where a simple temporal comparison process operates and the frequency at which the spectral cues becomes prominent.

Dai and Green

Our second effort in this area is represented by the joint work of myself and Dr. Huanping Dai. Consider the following profile condition. The standard is a logarithmically spaced spectrum consisting of 21 components, 200 to 5000 Hz, all of equal amplitude. The signal is an increment in the central, 1000-Hz component. Also, recall that the overall level of the complex is a random variable, so that absolute levels of any components contain little information about the presence or absence of the signal.

In what we might call a control condition, the standard is presented simultaneously with the signal; both are presented for 500 msec. If the standard alone is presented, it also has a duration of 500 msec. In the experimental condition, the only change is when we start the signal (1000 Hz) component relative to the onset of the other 20 components of the profile. In the standard alone condition, all 21 components are equal in amplitude. If the signal is added to the standard, then the 1000-Hz component is presented at a slightly higher level than the other 20 components. Note that in the experimental conditions, the information in the 500-msec interval when all components are present is identical to the information presented in the control condition. The results are startling. If the signal component precedes the onset of the 20 other components by 50 msec, the signal is harder to detect by about 15 dB!

Introspectively, the salient difference between the two conditions is that if the signal component's onset precedes the onset of the other 20 components, then it appears segregated from the remaining profile components, and it is difficult to compare the level of the signal component with the level of the other components of the complex. When all components start together, a single complex entity is heard, and differences in the quality of that solitary sound reveal the presence or absence of the signal. While such introspection is interesting, we need a more quantitative description of these phenomena.

We have been exploring the following approach. Naturally, the critical comparison is between the level of the 1000-Hz component and the other 20 components of the profile. The preceding results are surprising only if one thinks of the level of a sound as a static quantity. Obviously, the stimulus levels are the same during the last 500 msec for both the control and experimental conditions. But suppose intensity level is coded in a dynamic fashion by the auditory system. Suppose the onset of any stimulus causes a time-varying response, $r(t)$. It may be difficult to compare the level of two different components unless they have similar onsets and offsets, because without temporal synchrony, the cross-correlation between the outputs is reduced. A reduction in this correlation makes it difficult to judge the relative level of the two. A simple example may make this point clearer. Suppose one is asked to judge the relative level of two sounds that are shaped by a sawtooth envelope. It will be easier to judge the relative amplitude of the two sounds if the sawtooths are in-phase rather than out-of-phase. This analysis of the problem provides, in theory, a more rigorous way to treat the problem of 'segregation' or 'auditory object' perception. We have been exploring this approach with the hope of developing some testable consequences of this hypothesis.

4. Profile Weights

As we indicated in our last progress report, we have been exploring the application of Dr. Berg's COSS (conditional on a single stimulus) analysis to a special form of the profile task.

Our early experimental results closely mimic the optimum decision strategy for a channel model of profile analysis such as that suggested by the MIT group (Durlach, Braida, and Ito, JASA 1986--or see Green, 'Profile Analysis' p. 113-125). One can show that, to a good first approximation, the optimum decision statistic, y, for a profile experiment task is

$$y = \Sigma\ a_j\ L_j \qquad \text{Eq. 1}$$

where the weight assigned to the signal component, $a_s = 1$, and the weights assigned to the nonsignal components are all a negative [1/(n-1)].

We included figures in the last report that showed data which closely mirror these optimum predictions. That research has been submitted and accepted for publication (Ref. 7). That paper should appear sometime in the fall of 1990.

Two new experiments represent a continuation of those efforts. First we measured profile weights for conditions where the signal was added to noncentral frequency components of the spectrum. We have known for some time that the listeners are most sensitive to changes in spectral shape if the change occurs on a frequency component located in the middle of a complex spectrum. Sensitivity is poorer if the change occurs at either end of the spectrum. A plot of the threshold values, threshold versus component frequency, resembles a bowl with the minimum threshold occurring at the central frequency region. The spectral weights measured for the noncentral components are very odd in appearance and do not follow the near-optimum weight pattern measured for the central components. The presence of nonoptimum weights would account for why the thresholds are higher at the noncentral frequencies. The remaining question is why are these weights so poor.

Finally, we have been exploring the pattern of spectral weights measured with a three-tone complex (center frequency of 1000 Hz) as we vary the frequency spacing between the components. Naturally, at the wide frequency spacing, the weights are nearly ideal, namely [-0.5, +1, -0.5], and the threshold for detecting an increment in the central component is fairly good (-10 to -15 dB). We expected that both the threshold for the increment and the optimum pattern of spectral weights would deteriorate as we moved the components closer together in frequency. Instead, we were surprised to find that the thresholds remained very good--the threshold for a spacing of 10 Hz between components is about -12 dB. The weight pattern was less clear with different observers showing different trends.

The reasons for these results are complicated. We believe that the cues used by the listener change as a function of frequency spacing between the components. We believe that no less than three different sets of cues are used by listeners to detect the change in the intensity of the central component. At the wide spacing, the listeners appear to be comparing the intensities of the middle and outer components (profile listening). At about 40-Hz spacing between components, however, a strong pitch cue is present. The signal is detected because the pitch of that three-tone complex is higher than the pitch of the equal-amplitude three-tone complex. We have evidence for this conjecture because thresholds are raised by 10 dB if we randomize the sampling rate of the D-A converters on each presentation--thus rendering the pitch cue less effective. Finally, at 10-Hz spacing, we believe the smoothness of the envelope becomes the dominate cue. We support this conjecture by the following experiment. The threshold increases if another AM waveform is present in the spectrum (at 4000 Hz) having a 10-Hz envelope frequency. This form of interference between amplitude-modulated waveforms was demonstrated by Yost and Sheft in a recent article (J. Acoust. Soc. Amer., 1989, Vol 85, pp 848-857).

Thus, three different cue systems are apparently employed by the listener in this simple three-tone task as we vary the frequency spacing between the components. The threshold, however, remains nearly the same. We hope to measure spectral weights for each of these three regions and determine if the pattern of weights can be used to infer differences in the modes of processing.

PERSONNEL

Dr. Bruce Berg continues to work in the laboratory. He joined us on June 1, 1988.

Dr. Virginia Richards moved to Philadelphia during the summer of 1989. She accepted a job as assistant professor in the psychology department at the University of Pennsylvania.

Tim Tucker continues as the electronics technician. He works half-time in the laboratory and spends the other half of his time working for his own company.

Zekiye Onsan has secured a H-1 visa and works part time for the Air Force grant as an engineer technician.

Quang Nguyen continues as a laboratory technician.

Mary Fullerton continues as the secretary and bookkeeper for the laboratory.

Jill Raney will defend her thesis in May.

Gregory Canfield, a recent graduate of Case Western, has joined the laboratory as a first-year graduate student. His undergraduate degree was in physics.

Dr. Sue Fallon finished her doctoral requirements at the University of Indiana. She joined us in August, 1989 and has worked two months on the Air Force grant. She began her NIH post doctoral fellowship in January, 1990.

Dr. Huanping Dai joined the laboratory October 5, 1989. He recently completed his degree in psychology at Northeastern University where he was supervised by Dr. B. Scharf.